October 1986

IN-33337

(NASA-CR-179879) FAR-INFRARED SPECTRAL STUDIES FROM THE G. P. KUIPER AIRBORNE OBSERVATORY Final Technical Report, 1 Oct. 1978 - 31 Oct. 1986 (Cornell Univ.) 8 p CSCL 03A G3/89

N87-11652

Unclas 43881

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Center for Radiophysics and Space Research

ITHACA, N. Y.

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FINAL TECHNICAL REPORT

for

NASA Grant NSG 2347

Far-Infrared Spectral Studies from the G. P. Kuiper Airborne Observatory

October 1, 1978 to October 31, 1986

Martin Harwit, Principal Investigator

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Introduction and Summary

The grant to carry out far-infrared spectral studies of astronomical sources from the G. P. Kuiper Airborne Observatory was first funded in October 1978 and officially ended on October 31, 1986. During these eight years, a variety of previously undetected spectral lines were discovered, and these were used to determine the physical and chemical conditions prevailing in regions of active star formation. They served to clarify the nature of the ionized hydrogen regions often adjacent to star-forming clouds, the characteristics of shocks which may signify the onset of star formation, and the nature of coolants that channel away energy thus enabling a cloud to collapse to form new stars.

The productivity of the eight years during which the grant has funded the research we carried out can best be measured by the publications that flowed from the work -- three Ph.D. theses and an additional 34 scientific papers, all told.

Brief Outline of the Scientific Work Accomplished

In the earliest days of the work supported by the grant, we completed investigations on a previous study to determine the far-infrared polarization of interstellar clouds -- in particular of the Orion cloud. We obtained upper limits of the order of 1 to 2% on the polarization of the Orion molecular cloud, a value consistent with later, more advanced observations by Prof. Roger Hildebrand's group at the University of Chicago.

Soon, however, our efforts converged on spectral line studies in the range out to 120 microns and eventually out to 180 microns. We studied the line emission of ionized hydrogen regions, by looking for emission in the brightest fine-structure lines of differently ionized species. Here, we concentrated on the 88- and 52-micron lines of O++, the 63- and 146-micron lines of neutral oxygen and eventually on the 157-micron line of C+. All of these spectral lines had first been found by our group through use of the Lear Jet, and we then availed ourselves of the larger telescope on the Kuiper observatory to follow up with more detailed mapping efforts. Each of these lines provided a different type of information. The 88-micron radiation was capable of providing line-of-sight column-densities of doubly ionized oxygen in the hottest parts of an ionized region. The added information obtained through 52-micron line observations provided data on the detailed local density. The neutral oxygen observations told us about conditions in the surface regions of the nebula, while the ionized carbon data gave insight into the physical conditions that characterize neutral hydrogen regions surrounding an ionized cloud. With these techniques we primarily studied H II regions, atomic hydrogen clouds, planetary nebulae and, in some instances planetary surfaces and even the rings of Saturn.

During the later years, our studies turned to the investigation of far-infrared molecular line emission. Here our concern was with understanding the nature of cooling mechanisms in interstellar shocks. Those shocks are believed to trigger the onset of star formation and, in turn, the formation of stars is thought possible only if gas clouds can radiate energy in order to collapse to an increasingly compact state -- the stellar state. We therefore studied the emission from rotationally highly excited CO molecules and from

OH radicals, both important constituents of shocked domains.

In all of these efforts we strove to develop the requisite theoretical models by means of which these emissions could be understood. In retrospect, the most important results -- observationally as well as theoretically -- that we were able to contribute include these:

o We were able to obtain the first overall energy budget estimate for an H II region/molecular cloud complex -- the Orion region in the immediate vicinity of the Kleinmann-Low molecular cloud. It elucidated the distribution in energy radiated, respectively, by heated dust, by the ionized gas cloud, by the neutral region surrounding the ionized domain, and by the molecular hydrogen shock.

o We discovered that a halo of gas of very large extent, consisting mainly of neutral hydrogen gas, surrounds many H II regions and cools itself through emission in the 157 micron C+ line.

o The oxygen 63-micron line in H II regions, but presumably many other atomic and ionic fine-structure lines as well, may possess considerable optical depth, and it is important therefore to analyze these emissions with radiative transfer techniques. For the neutral oxygen gas, we theoretically modelled the Orion Nebula to fit our observations in the 63- and 146-micron emission lines.

o Conditions in shocked neutral clouds, particularly in the post-shock domain, can be determined with some specificity if a combination of OH and CO emission lines are observed. We investigated both the observational studies and their theoretial consequences for the Orion Nebula.

Along instrumental lines, four further major advances may be highlighted, though there were many smaller advances in a continuing effort to increase both instrumental sensitivity and resolving power. These advances included:

o The construction of a novel all-reflecting-optics interferometric spectrometer for use in the far-infrared and submillimeter domain.

o Construction of a novel, highly compact, mechanically simple, high-resolution, Fabry-Perot/grating spectrometer for the submillimeter domain.

o First application in astronomy of stressed gallium-doped germanium detectors that had been developed by Prof. Paul Richards at the University of California at Berkeley. These detectors permitted our group to carry out the earliest investigations of spectral lines in the 120- to 180-micron region, including investigation of the astrophysically important 157-micron C+ line.

o Participation in the design of a facility spectrometer for far-infrared work constructed at NASA/ARC for use aboard the Kuiper Airborne Observatory.

Not falling into any of these categories were services volunteered by the principal investigator who served as Chairman of the Airborne Observatories' Users Group and worked with Users and NASA/ARC staff in that capacity for two and a half years.

Much more could be written to describe the work carried out under this

grant. The publications listed below, however, bring full details of the work and speak for themselves.

Participants:

Scientific and professional staff and students who participated in work carried out under this grant, for all or part of its duration, were:

Martin Harwit, professor of astronomy
Ray W. Russell, post-doctoral research associate
Timothy Gosnell, graduate student
Gary Melnick, graduate student
Gordon Stacey, graduate student
Paul Viscuso, graduate student
Charles Fuller, computer specialist, research support specialist
George Gull, engineer, research support specialist
Noel Kurtz, mechanical engineer, research suppport specialist
Scott Smyers, computer speciliast, research technician
Cynthia Burgess, undergraduate student
Chris Hillman, undergraduate student
Joshua Klein, undergraduate student
Andrew Reimanis, undergraduate student
Sylvia Corbin, administrative aide

Ph.D. Recipients:

The three recipients of Ph.D. degrees were:

- o Gary Joel Melnick -- Far-Infrared Fine-Structure Line Studies of Galactic Nebulae (1981). Dr. Melnick now is at the Smithsonian Astrophysical Observatory, Cambridge, MA, and an occasional guest observer on the KAO.

- o Gordon John Stacey -- Far-Infrared Line Emission from the Galaxy (1985). Dr. Stacey now is in the Physics Department at the University of California, Berkeley, and regularly conducts research flights on the KAO.

- o Paul Joseph Viscuso -- Observations of Far-Infrared Molecular Emission Lines from the Orion Molecular Cloud (1986). Dr. Viscuso, who just finished his thesis recently, is at the Five College Radio Astronomy Observatory, University of Massachusetts, Amherst, MA. He plans to apply for guest observing time on the KAO on the next go-around.

The Future

Cornell University has made an agreement with NASA's Goddard Space Flight Center to loan their researchers our novel "Hinge (Fabry-Perot/grating) Spectrometer" developed here. It will be further developed there, most probably to operate in the 300-micron region and will then be proposed for flights aboard the KAO.

Budget

The grant was awarded $869,627 over the eight years of its duration. No unspent funds remain in this budget.

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"Far-Infrared Fine-Structure [OI] Transitions at 145μ in the Orion Nebula, G. Stacey, N. Kurtz, S. Smyers and M. Harwit, read at AAS meeting, Troy, NY, May 1982.

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